Fermi National Accelerator Laboratory

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Tickling C:AQ7

C.D. Moore and H. Pfeffer

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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1. Introduction

The alignment of the quadrupoles in a proton synchrotron is important and the alignment of the low beta quadrupoles in collider mode is even more critical. One of the important considerations is the relationship of the electrical center of the Beam Position Monitors (BPMs) to the magnetic center of quadrupoles. Determining this involves measurements when the elements are not in the tunnel and careful alignment utilizing external reference marks when the BPMs are not physically attached to the quadrupole. Even when the BPM is attached to the quadrupole (and calibrated), systematic offsets can be introduced by cable mismatch or slight imbalances in the monitoring electronics. A method has been implemented at Cern [1,2] to determine this relationship using the beam itself.

This paper will describe a proof of principle experiment at the Tevatron using one of the individually powered quadrupoles near the B0 interaction region whose ACNET name is C:AQ7.

2. Principle of k-modulation

If the beam is off center in a quadrupole of length L, located at s_o, then changing the strength k of the quadrupole will give a local kick to the beam. The kick $\Delta x'$ is proportional to the displacement x of the beam from the magnetic center of the quadrupole:

$$\Delta x'(s_o) = \Delta k * L * x(s_o) \qquad (1)$$

The change to the closed orbit at a location s due to this kick is given by:

$$\Delta x(s) = \sqrt{\beta(so)*\beta(s)}\ \frac{*\ \cos[\ |\mu(s)\ -\ \mu(s_o)|\ -\ \pi Q]\ \ *}{2*\sin(\pi\ Q)}\ \Delta x'(s_o) \qquad (2)$$

where β,μ, and Q are the betatron function, phase advance, and tune in the plane of motion under consideration. Cern has developed the idea of harmonically modulating the strength of the quadrupole at a fixed frequency well below the synchrotron frequency and betatron frequency:

$$\Delta k = \Delta k_o * \sin(\omega\ \ t) \qquad (3)$$

3. Experimental Setup

The C:AQ7 power supply was modified as shown in figure 1. A simple KROHN-HITE 5200 signal generator was used to apply a 6.5 Hz signal to the modulation input connector. The magnitude of the applied modulation signal was .3% of the nominal current at 150 GeV and .13% at 900 GeV.

One of the unique features of the experiment was that we simply used the normal BPM system, taking our signals from the front panel of the R. F. module. We were able to observe the applied modulation by putting the BPM signal directly into an HP3561A signal analyzer. However, to get a cleaner signal we utilized a customized crate which uses the intensity signal from the RF module to trigger a sample and hold on the position signal at the proper time in the position processing. A schematic of the data acquisition system is shown in figure 2.

The beta functions and phases of the BPMs in the A4 region are shown in table 1:

Location	βx (meters)	$\Delta\Phi x$ (degrees)
A42 BPM	96	-118
A44 BPM	97	-50
AQ7 A46	160	0
AQ5 BPM A48	132	138
AQ1 BPM A49	145	150
AQ4 BPM USB0	38	165

Table 1.
Horizontal phases and βs

4. Data Acquisition and Analysis

Previous studies [3] have shown a number of low lying frequencies in BPM spectra arising from various vibrational modes of quadrupoles, and we wish to avoid these frequencies. Another consideration is that the low beta quadrupoles are superconducting and we do not wish to quench them; this implies that we should use as low a frequency as possible.

The first attempt at modulating the beam was on 12/7/96 at 150 GeV using 6 coalesced bunches and figure 3 shows the Fourier spectrum from 0 to 10 Hz of the horizontal BPM at A48 with the modulation frequency set at 6.5 Hz. The low lying comb of frequencies are due to the Main Ring ramp and it is obvious why 6.5 Hz was chosen.

No attempt was made to move the beam to null out the signal. However we did take the time to make an interesting set of measurements; namely we measured the magnitude of the 6.5 Hz signal on all the BPMs in the A4 house. We then compared the relative response of the closed orbit due to a radial motion of C:AQ7 {as calculated using page W120 (J. Holt) or equivalently by using formula 2 and table 1}. The results shown in figure 4 are clearly suggestive that we are measuring a closed orbit distortion due to modulating the C:AQ7 quadrupole.

On 1/4/96 we were able to perform a complete experiment in the sense of moving the closed orbit at A46 (C:AQ7) to null out the 6.5 Hz signal. From figure 4 it appears that the A42 BPM would have more sensitivity than the A48 BPM so we chose to monitor its response. This was done during a 900 GeV store and figure 5 shows the starting spectrum. There are several interesting points to observe between figures 5 and figure 6(which has HPA42 at 150 GeV). First, the magnitude of the 4.6 Hz (due to the Central Helium Liquifier Plant - see reference 3 for details) is the same ,apologies for the slightly different scales, which implies that the result is due to quadrupole motion. Second, the magnitude of the signal due to the Main Ring is lower which implies that the effect from the Main Ring is due to a direct coupling of magnetic flux to the TeV beam and not to a rocking of TeV quadrupoles which would be independent of momentum (all other things being equal).

Figure 7 shows the spectrum when we have nulled out the signal and in conjunction with figure 5 clearly shows qualitatively that the method works. However, the real proof is given in figure 8 which clearly shows the linear response of the magnitude of the 6.5 Hz signal with position at C:AQ7. The line shown is a fit to the absolute value of the position as measured by page T39 minus an offset, times a scale factor. The value of the offset (in this case -.93 mm) gives the difference between the magnetic center of the quadrupole as determined by this method and the value assumed by page T39. The l.s.b. of the digitizer system is .15 mm and this method appears to offer an opportunity to determine the offset to better than this.

As a further consistency check we can calculate the slope of the line in figure by combining equations one through three (using table 1):

$$\Delta x(s) = 64.3\text{m} * \Delta k_o * \sin(\omega t) * L * x(s_o). \tag{4}$$

Using the value of the modulation for 900 GeV, $\Delta ko = 1.3E\text{-}3*k$, the magnetic length L of .635m from the low beta design book [4], and the transfer constant of .5825T/cm/kA from the design book, we find

$$\Delta x(s)/x(s_o) = 64.3\text{m} * 1.3E\text{-}3/(1.414*103.1\text{m}) = .0006 \tag{5}$$

where we have used a factor of the square root of two to take into account the fact that the signal analyzer gives us the RMS value of the position. The best fit value from the measured data for the slope is .0007. This is good agreement since we were not really concerned with the absolute value of this number and did not record input values with great care.

5. Conclusion

We have successfully determined the magnetic center of the C:AQ7 quadrupole with respect to a near by BPM by modulating (tickling) the current in the quadrupole without quenching the magnet.

Another attractive possibility is to tickle the AQ5 quadrupole because there are both horizontal and vertical BPMs associated with this quad and it is possible to do a 3 bump at Q5 both horizontally and vertically. We know the Q5 on the B side will also be changed but we may still be able to see a minimum signal as opposed to a (hopefully) zero.

Location	βx (m)	$\Delta\Phi$x (deg)	βy (m)	$\Delta\Phi$y (deg)
AQ5	131	0	14	0
A42 BPM	96	-255		
A45 BPM			97	-131
AQ4 BPM			31	80

Table 2
Phases and βs for AQ5

If we are successful with the Q5 quadrupole we would then move on to one of the triplet quads probably Q3.

Acknowledgments

We would like to thank J. Seraphin for help in setting up the experiment at A4, M. Martens for moving the closed orbit during the experiment, and M. Olson for building the customized BPM sample and hold crate.

References

[1] I. Barnett et al,"Dynamic Beam Based Calibration of Orbit Monitors at LEP", to be published in the Proceedings of the Fourth International Workshop on Accelerator Alignment, KEK,Japan, November 14-17,1995.

[2] R. Schmidt, "Misalignments from k-modulation", Proceedings of the Third Workshop on LEP Performance, CERN SL/93-19 (DI) 1993, pp. 139.

[3] C. D. Moore, "Vibrational Analysis of Tevatron Quadrupoles" to be published in the Proceedings of the Fourth International Workshop on Accelerator Alignment, KEK,Japan, November 14-17,1995. Fermilab TM 1959.

[4] E. Malamud ,editor, "Tevatron Low-Beta Quadrupoles, July 25, 1988

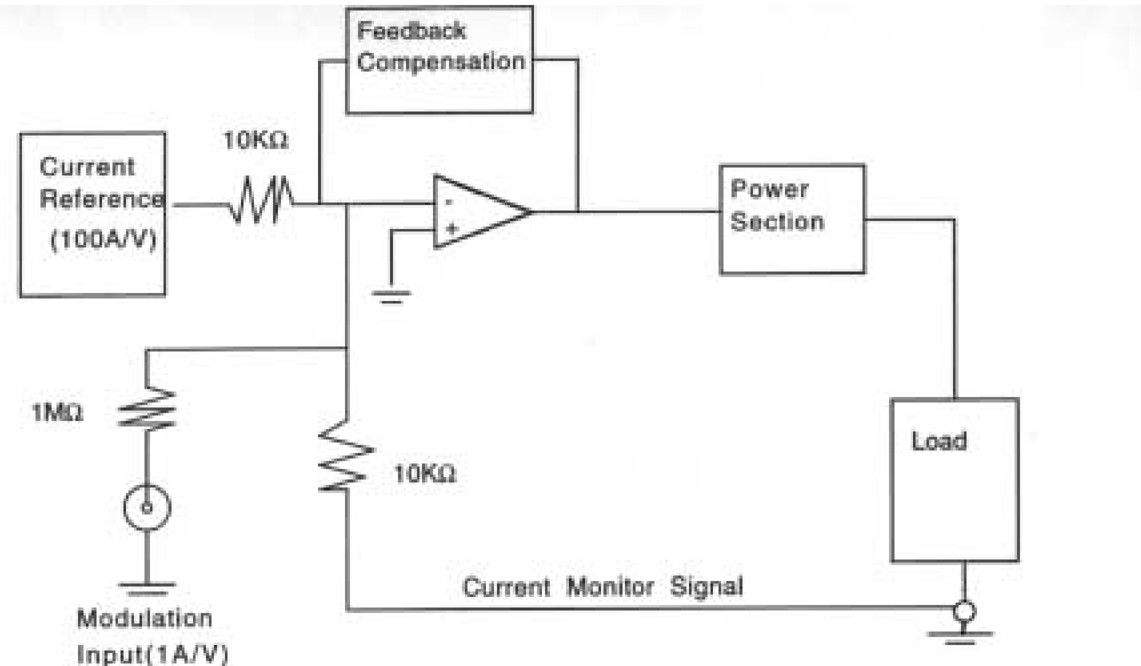


Figure 1.
Power Supply Modulation Set-up

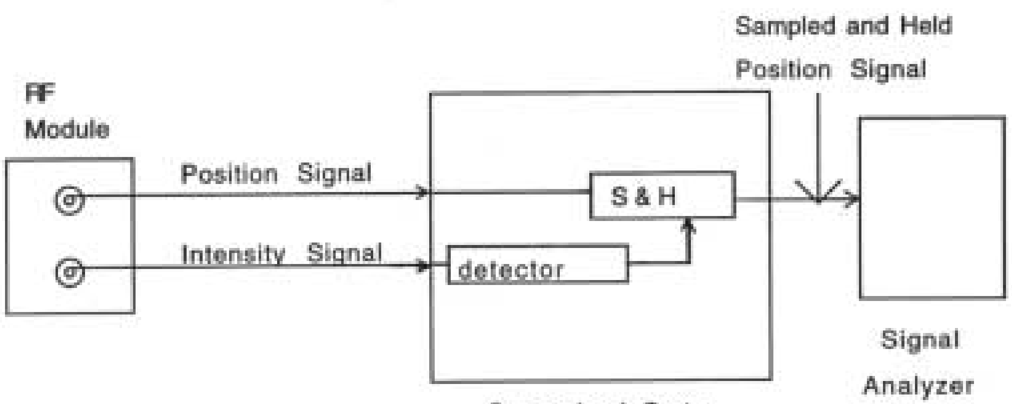
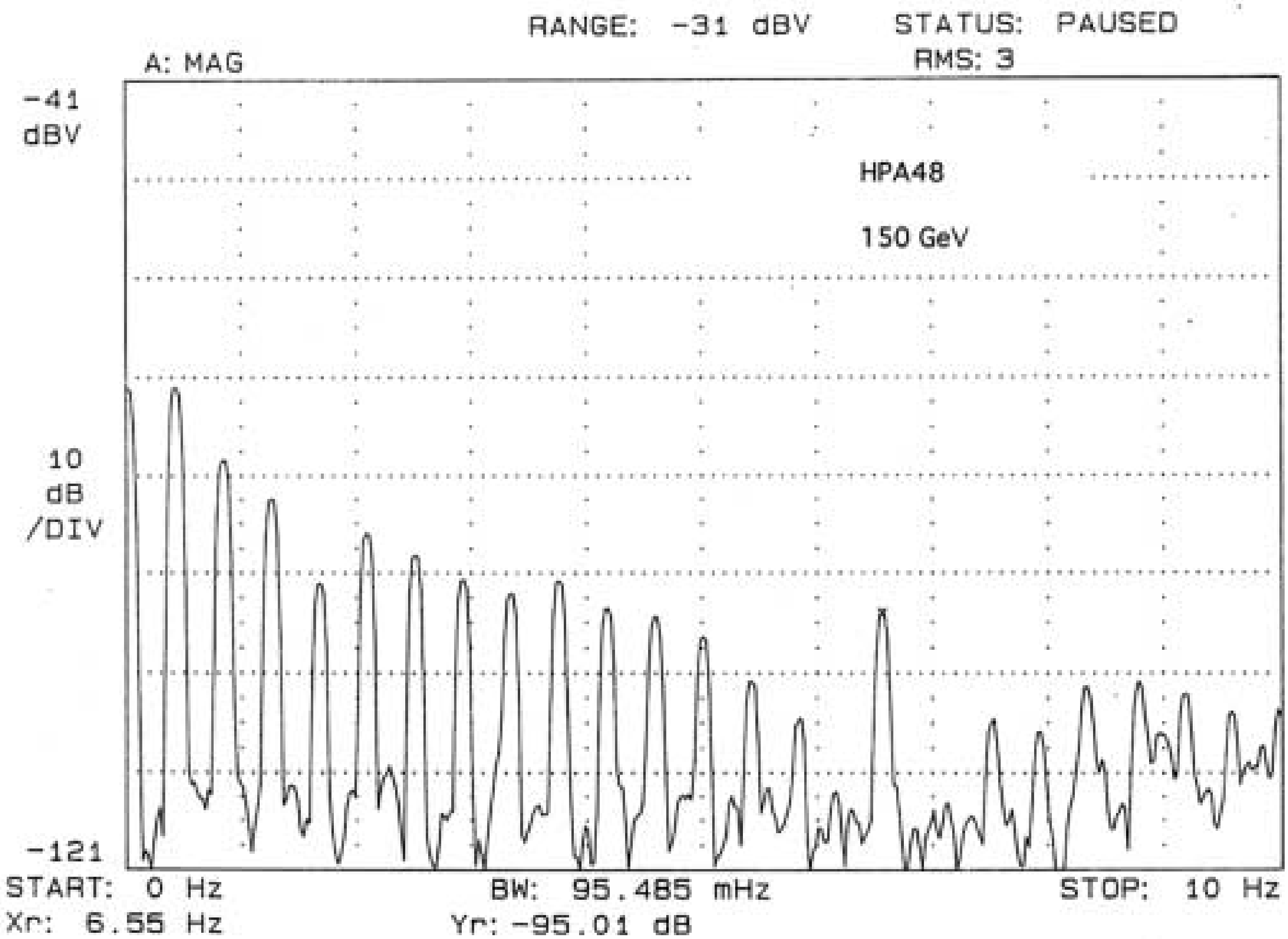


Figure 2.
Data Acquisition System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STATUS: PAUSED
A: MAG
RMS: 3
-41
dBV
HPA48
150 GeV
10
dB
/DIV
-121
START: 0 Hz
BW: 95.485 mHz
STOP: 10 Hz
Xr: 6.55 Hz
Yr: -95.01 dB

Figure 3

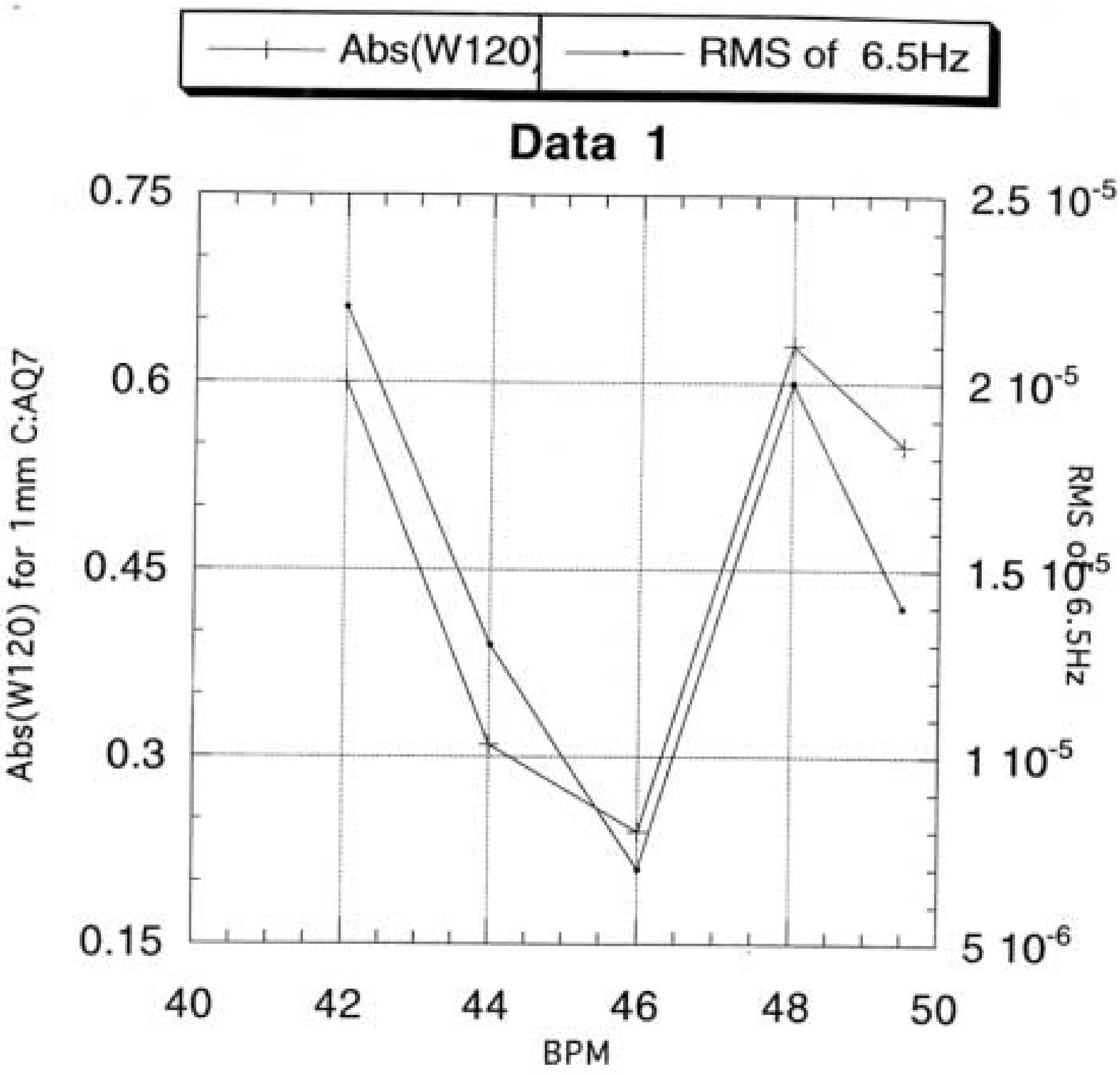

Abs(W120)
RMS of 6.5Hz
Data 1
0.75
0.6
0.45
0.3
0.15
2.5 10-5
2 10-5
1.5 10-5
1 10-5
5 10-6
Abs(W120) for 1mm C:AQ7
RMS of 6.5Hz
40
42
44
46
48
50
BPM

Figure 4

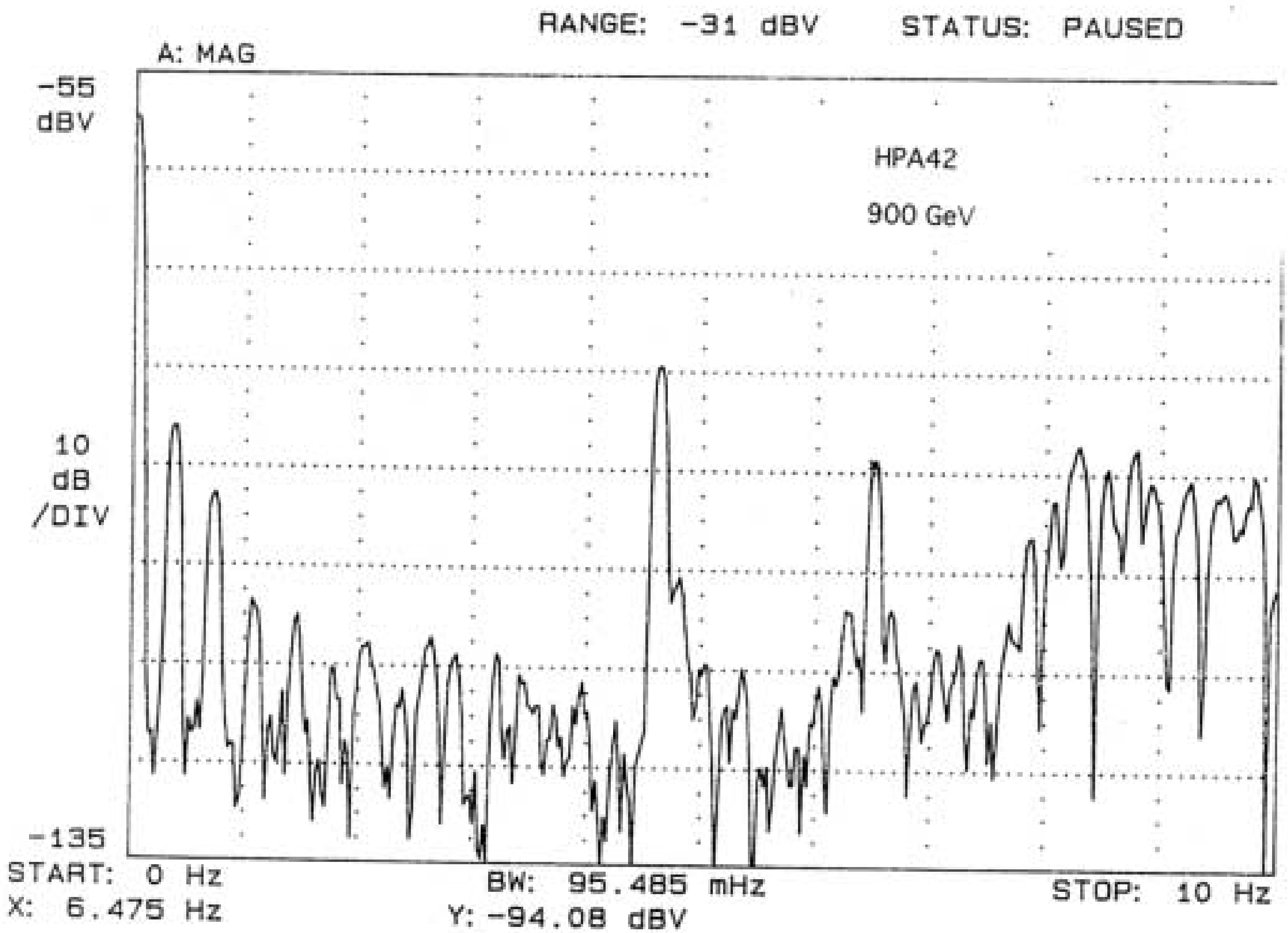
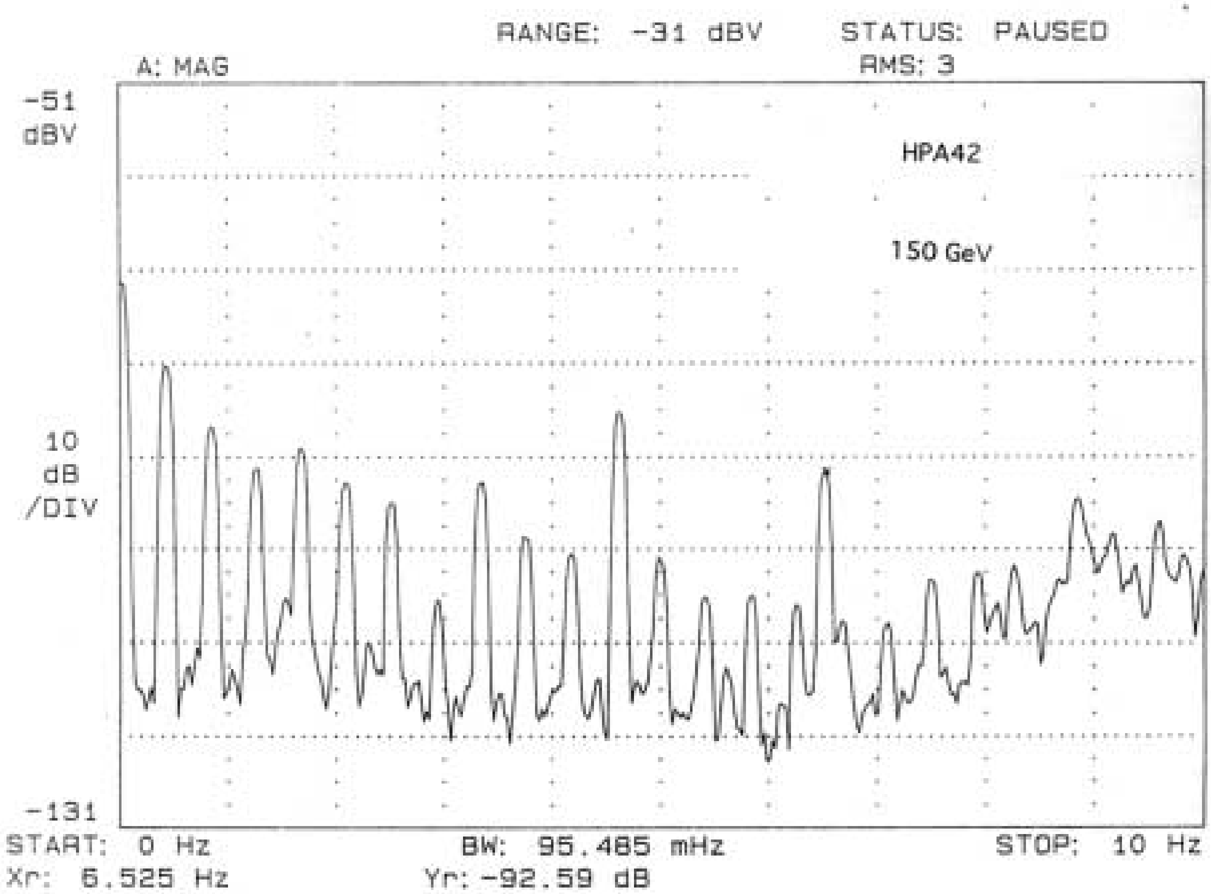

RANGE: -31 dBV
STATUS: PAUSED
A: MAG
-55
dBV
HPA42
900 GeV
10
dB
/DIV
-135
START: 0 Hz
X: 6.475 Hz
BW: 95.485 mHz
Y: -94.08 dBV
STOP: 10 Hz

Figure 5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STATUS: PAUSED
A: MAG
RMS: 3
-51
dBV
HPA42
150 GeV
10
dB
/DIV
-131
START: 0 Hz
BW: 95.485 mHz
STOP: 10 Hz
Xr: 6.525 Hz
Yr: -92.59 dB

Figure 6

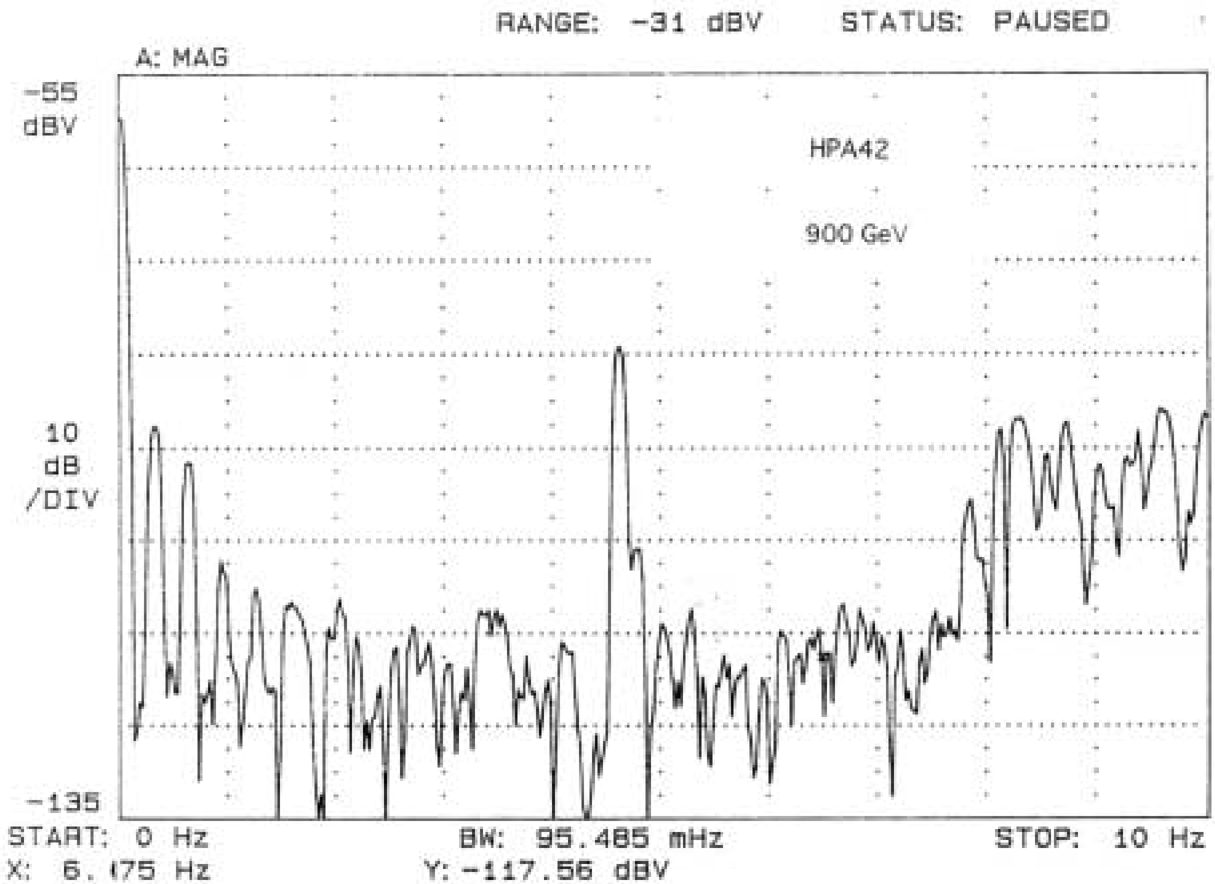
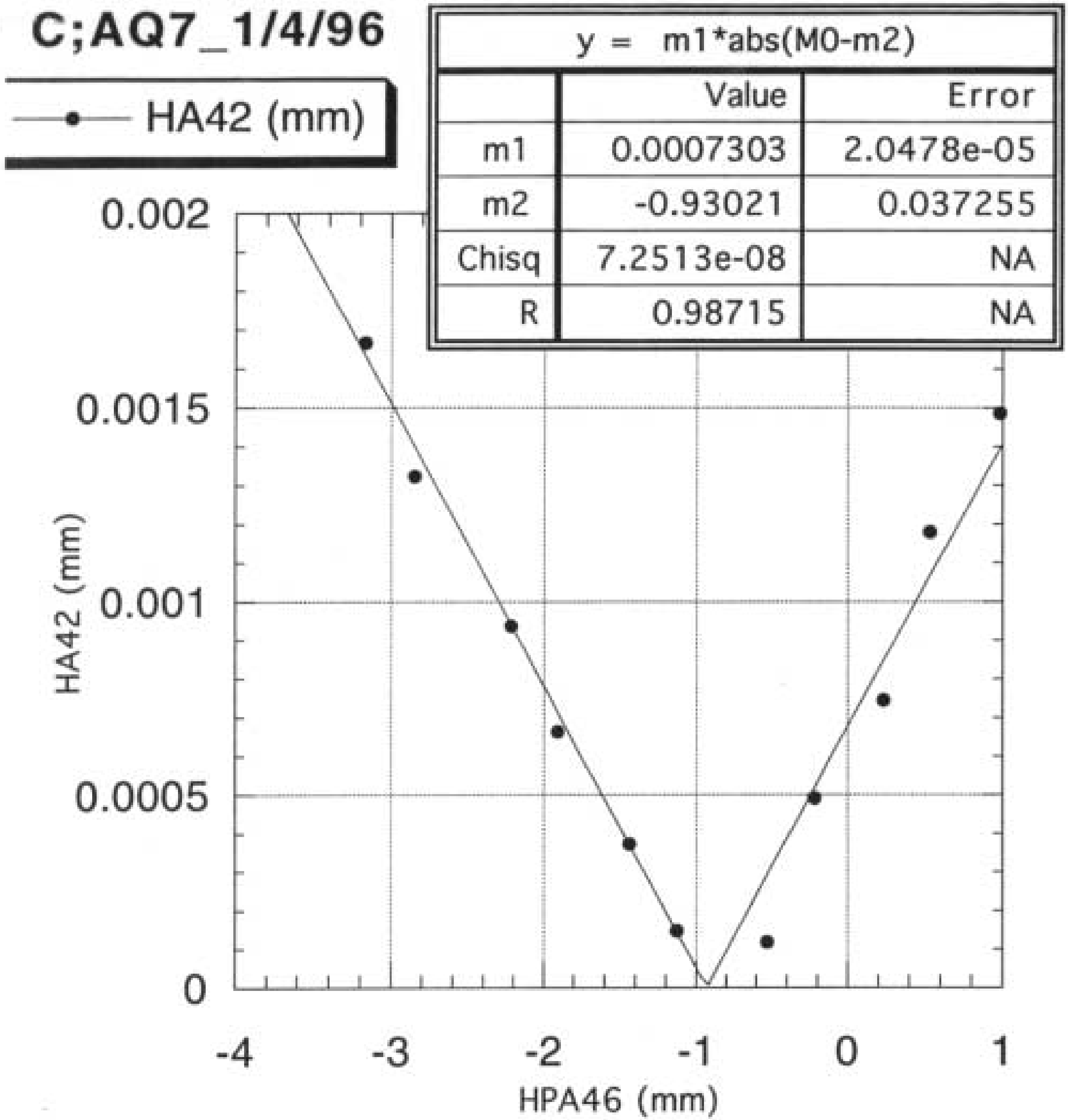

RANGE: -31 dBV STATUS: PAUSED
A: MAG
-55
dBV
HPA42
900 GeV
10
dB
/DIV
-135
START: 0 Hz
BW: 95.485 mHz
STOP: 10 Hz
X: 6.(75 Hz
Y: -117.56 dBV

Figure 7



y = m1*abs(M0-m2)		
	Value	Error
m1	0.0007303	2.0478e-05
m2	-0.93021	0.037255
Chisq	7.2513e-08	NA
R	0.98715	NA

Figure 8